Technical Report on ONR Grant No. N00014-95-1-0323
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RECENT ACCOMPLISHMENTS

by D.J. Kaup and his research group

First, we will briefly describe our recently submitted, accepted, or published results. Then afterwards, we shall delineate our current and future works.

1. Stimulated Raman Scattering by a Point-like Medium - Classical and Quantum Treatments, D.J. Kaup, A.E. Kozhekin, and V.I. Rupasov. Phys. Rev. A **53**, 573-85 (1996). In this paper, we have studied the quantum nature of the SRS problem when the medium is short compared to the length of the envelope of the pump (which is the experimental situation). In addition to accounting for the pump depletion, we have also presented means for evaluating the expectation values of the intensity, medium excitation and phase correlations.

2. Exactly Solvable 1D Model of Resonance Energy Transfer, D. J. Kaup and V. I. Rupasov J. Phys. A **29**, 2149-62 (1996). In performing the research on the above manuscript, we also found a means for solving the one–dimensional quantum two–level problem for the emission and absorption of radiation in such a manner that one can maintain causality.

3. Exactly Solvable 3D Model of Resonance Energy Transfer, D. J. Kaup and V. I Rupasov, (to appear in J. Phys. A). Here we extend the above work to three dimensions. Again we show that causality can also be preserved in three dimensions by suitably renormalizing the wave functions. These results and predictions could be tested in lightly doped glasses, where the dopant atoms had resonant levels at the frequency of light being used.

4. Optimum Reshaping of an Optical Soliton by a Nonlinear Amplifier, Sergey Burtsev, D.J. Kaup and Boris A. Malomed, JOSA B **13**, 888 (1996). In this paper, we show that there is an optimum set of parameters for a nonlinear amplifier such that the radiation generated and lost is a minimum.

5. The Control of the Center Guided Soliton by the Sliding Frequency Filter, S. Burtsev and D.J. Kaup. (to appear in JOSA B). This paper is the first to use second–order soliton perturbation theory to analyze the growth and behavior of the continuous

spectra due to an array of sliding frequency filters for a center–guided soliton in an optical fiber. The major result, not only for amplitude sensitive amplifiers, but also for phase–sensitive amplifiers, is that there is a restricted range in which the amplification will be stable. The two limits are simply that if one slides the frequency too fast, then one may lose the soliton, and if one slides it too slow, then the radiation which is created at each amplification can grow and saturate. In this paper, we compare our theory with numerical and experimental data from AT&T Labs.

6. The Damped/Amplified Nonlinear Schrödinger Soliton, D.J. Kaup and S. Burtsev, (Submitted to Physica D). How well could the variational method model a damped and/or a pumped NLS soliton? Here we compare the four possible methods for treating this problem: i) scattering data from the inverse scattering transform; ii)perturbation theory for solitons; iii) variational method; and iv) numerical solution of the exact PDE. The results for each method is compared and the best approximation for large times was the variational method.

7. Interactions between Polarized Soliton Pulses in Optical Fibers: Exact Solutions, M. Karlsson, D. J. Kaup and B. A. Malomed, Phys. Rev. E **54**, 5802-8 (1996). Optical soliton pulses have been proposed for optical communications through optical fibers. Such solitons would have approximately the same amplitudes and velocities, which means that as scattering data in the IST (inverse scattering transform), they correspond to degenerate bound state eigenvalues. Such solitons will not form a bound state, however they do experience a very weak attractive force from each other. Thus they separate as $\ln z$ and not linearly in z, as do solitons with unequal velocities.

8. Asymptotic Behavior of N–Soliton Trains of the Nonlinear Schrödinger Equation, V. S. Gerdjikov, D. J. Kaup, I. M. Uzunov and E. G. Evstatiev (to appear in Phys. Rev. Lett.) Consider again a train of solitons, all of almost equal amplitudes and velocities, and all well separated from one another. In this case, one can determine the evolution of these solitons by simply evaluating the nonlinear interaction due to the small overlaps of the tails. When one does this, he can reduce the equations for the pulse centers and amplitudes to a set of ODE's, which are now a set of lattice equations, which then can be identified with a complex Toda lattice, which is again integrable. Thus one can now assume various initial arrangements of soliton pulses, then use the integrable complex Toda lattice equations to determine the asymptotics. Using t
could then identify what initial phasing and amplitude variations would be the most stable and/or unstable.

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9. Asymmetric Solitons in Mismatched Dual-Core Optical Fibers, D.J. Kaup, T.I. Lakoba and Boris A. Malomed (accepted by JOSA B). This was an ambitious variational calculation to test if the variational method could predict new solitary waves. We used the method to determine possible solitary wave solutions for a Dual-Core fiber with an arbitrary mismatch between the cores. We then numerically verified, with exact numerical solutions, several of these solitary waves. This has validated this method, and also revealed a new type of a continuous-solitary wave, best described as a solitary wave setting on top of a harmonic wave, and which we termed as a "delocalized solitary wave". Standard numerical solutions would not have been able to find these solutions. Although they are usually unstable, we suspect that they may be important and useful as transient states in a coupler.

10. Degenerate Two–Photon Propagation and the Oscillating Two–Stream Instability: General Solution for Amplitude-Modulated Pulses, H. Steudel and D.J. Kaup, J. Mod. Optics **43**, 1851-66 (1996). With femtosecond pulses becoming a reality, the feasibility of using various four–wave interactions is becoming practical. One of these four–wave interactions is the process known as "two–photon propagation" (TPP). There is a degenerate case of TPP where the pump and the decay wave are identified, causing the reaction to occur very rapidly, which is the reason for the experimental interest in this particular process. This paper shows that this process can generate unlimited pulse compression when there is only amplitude modulation. It also shows how to solve these equations in general, as long as there is no phase variation (frequency shift) across the pulse.

11. Solutions of Degenerate Two–Photon Propagation from Bäcklund Transformations, H. Steudel, R. Meinel and D.J. Kaup (Accepted by J. Mod. Optics). For the interaction described above, there also exist Bäcklund transformations for this problem, since these equations are integrable. Here we detail various solutions obtainable by the Bäcklund transformation.

12. The Squared Eigenfunctions of the Massive Thirring Model in Laboratory Coordinates, D. J. Kaup and T. I. Lakoba, J. Math. Phys. **37**, 308-23 (1996). There are models for interacting nonlinear optical beams that have the massive Thirring model as one limit. This result allows us to develop a singular perturbation theory for such limits, which can provide additional information about such models.

13. Variational Method: How It Can Generate False Instabilities, D. J. Kaup and T. I. Lakoba, J. Math. Phys.**37**, 3442 (1996). The utility and confidence of information

obtained from the Rayleigh–Ritz variational method can vary, depending of the validity of the trial functions used. Here we study the possible generation of false instabilities due to a poor choice of trial functions. We are able to show that for the NLS and the vector NLS, one may easily avoid any and all false instabilities. However for models related to the massive Thirring model, there is always the possibility of a false instability occurring (a false instability is where the variational method gives an unstable mode, when in actuality there is none).

14. How the Variational Method Can Give Rise to False Instabilities, D. J. Kaup and T. I. Lakoba, "Nonlinear Physics: Theory and Experiment", pp. 169-76, Eds: E. Alfinito, M. Boiti, L. Martina & F.Pempinelli [World Scientific, New Jersey, 1996]. This is a conference report on our results regarding false instabilities.

15. Solitons in Nonlinear Fiber Couplers with two Orthogonal Polarizations, T. I. Lakoba, D. J. Kaup and Boris A. Malomed (submitted to JOSAB). This is mostly the work of Dr. Lakoba, who successfully applied the variational method to a very complex, four component system. He has delineated the possible solitary waves, their probable stability, and interpreted the structure of the solitary waves as various parameters change.

16. Stationary Electron Density Profiles in Crossed–Field Vacuum Devices, D.J. Kaup and Gary E. Thomas (submitted to J. Plasma Phys.) There is an old classical problem of how to calculate the electron density profile for an operating magnetron or crossed-field amplifier (CFA). Here we show that one can numerically solve the nonlinearly coupled equations for the density profile and the RF waves, and then numerically determine the stable electron density profile as well as the resulting current density. Numerical data agrees reasonably well with experiments. Figures are shown of the composite solution for the density, which show distinct spokes, well known from particle simulations.

17. Excitation of Upper–Hybrid Waves from O–Mode Electromagnetic Waves Via Density Gradient in the Ionosphere, S. N. Antani, D.J. Kaup and N.N. Rao, J. Geophysical Research **101**, 27,035-041 (1996). Plasma physics contains lots of nonlinearities, however there are few which are cleanly accessible to experiments. One of these is the interaction of O-mode and upper-hybrid waves in ionospheric heating experiments. In the process of heating the ionosphere, density profile changes will occur, as in our above work on nonneutral plasmas (magnetrons). This paper shows that at the upper hybrid resonance, during a heating experiment, significant pump depletion and/or density profile changes must occur.

Work in progress.

1. The Inverse Scattering Transform for Degenerate W–Problems, D.J. Kaup and H. Steudel. (in preparation). Here we look at solving the degenerate TPP equations when there is a phase variation across the pulse. We are finding that any phase variation will limit the pulse compression.

2. On the Inverse Scattering Transform for the Benjamin-Ono Equation. D. J. Kaup and Y. Matsuno,(in preparation). Prof. Matsuno is visiting Clarkson for 10 months. During this time, we have and will study the inverse scattering transform (IST) for the Benjamin-Ono (BO) equation and the soliton solutions for deep water. We find that the current status of this IST is incomplete. The scattering data is under determined, with additional relations needed to exactly specify it. We are currently formulating this IST properly, so that we may look at perturbations of BO soliton interactions in deep water.

3. Linear Stability of Multiple Internal Solitary Waves in Fluids of Great Depth, Y. Matsuno and D. J. Kaup (in preparation). Here we show that N-soliton solutions are stable and we also formulate a perturbation theory for them.

4. Soliton Perturbation Theory for the Manakov Model, D. J. Kaup and T. I. Lakoba (in preparation). For solitons in optical fibers, the correct equation to use is the Manakov system with perturbations. Dr. Lakoba is working on developing the perturbation theory for this system. We are using it to evaluate the effects of random changes in the polarization and phase velocities on soliton propagation.

5. Noise Suppression near an NLS Soliton, D. J. Kaup and T. I. Lakoba (in preparation). Experiments have noted that near and around a soliton, the amplitude of the noise spectrum is decreased. We are using the NLS perturbation theory developed previously by this PI to study this noise problem.

6. Efficient Pulse Compression by Upconversion, D.J. Kaup, A. Struthers and E. Ibragimov, (in preparation). With these other authors, we have determined that the upconversion process of the three-wave resonant interaction (3WRI) seem to successfully explain certain recent experiments in pulse compression and frequency conversion.

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13. ABSTRACT (Maximum 200 words)

This report describes recent publications of Prof. Kaup and associates. The research areas covered include nonlinear optics solitions in optical fibers, dual-core fibers, and applications of the variational method to the above.

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